Thoughts of a Design Team: Barriers to Low Carbon School Design

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Abstract
With the increasing threat of serious climate change, various governments are aiming to substantially reduce their carbon emissions. In the UK all new schools and domestic buildings are required to be 'zero-carbon' from 2016. Schools are seen as community centres of activity and learning by local authorities, as such there is an emphasis to make schools exemplar buildings within the community and demonstrate best practice with regards to low and zero-carbon design. This paper focuses on what are the pertinent drivers and obstacles to low carbon school design based upon literature review and a survey of experts in the field. We find that more barriers are identified than drivers for low carbon design, with the greatest drivers being legislation, environmental concerns and running costs. The greatest barriers were identified as increased equipment in modern schools, complexity of building systems and the perceived extra cost of low carbon design and technologies. It is suggested that most barriers could be overcome by improving communication between the design team, client and end users, and that truly integrated design teams are the key to mainstream low carbon school design.

Keywords
Zero carbon, Low carbon, sustainable, school, design, barriers,

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) warns of significant warming resultant changes to weather patterns as a result of anthropogenic carbon emissions. The UK Government is committed to an 80% reduction in carbon dioxide (CO_2) emissions from 1990 levels by 2050 (HMSO, 2008) and the Kyoto protocol encourages other countries to adopt similar reductions in CO_2 emissions. Buildings are responsible for over 40% of energy use in most countries and are responsible for ~30% of global carbon emissions (WBSCD, 2008). A UK Government study (BIS, 2010) has shown that the UK building industry has the ability to influence ~298Mt CO_2, this equates to nearly 56% of all CO_2 emission in the UK (BIS, 2010). Clearly the building industry is an important source of carbon emissions for the UK and other countries and needs addressing. In an effort to meet its legally binding carbon reduction commitments, in 2008 the UK government set an ambition for new schools and domestic buildings built from 2016 to be 'zero carbon' (CLG, 2008) (although new legislation may push the deadline for schools back to 2019 to match the EU Energy Performance of Buildings Directive). While the exact definition of 'zero carbon' in this case is yet to be finalised there is clearly an impetus to significantly reduce carbon emissions of new buildings in the near future. In this paper the terms low carbon and zero carbon refer to in-use carbon emissions rather than the carbon emissions associated with their construction (embodied carbon). This was decided from the standpoint that buildings last a long time and the cumulative in-use carbon emissions over the buildings lifetime are far greater than the embodied carbon, this can be inferred from the figures presented by the UK Government (BIS, 2010). There has been a lot of focus on producing low or zero carbon homes, with for example, research conducted on the feasibility of zero carbon homes (Osmani & O'Reilley, 2009) as well as case studies of zero carbon designs (Wang, Gwilliam & Jones, 2009). Off the shelf zero-carbon homes are even available for purchase (ZED Factory). However, schools are larger, more complex and low or zero carbon schools are not often the subject of academic research. Schools are a central part of a community, acting as hubs of learning and also often as focal points within a community through their use out of hours for other activities, such as adult learning, art and crafts and exercise classes. These extracurricular activities now influence the design of new schools, as a result of the influence of the local council (acting as the client). A government report (DCSF, 2009) suggested that schools have the potential to become beacons of good practice within a community able to inspire sustainable behaviour not only through learning but also by example and engaging with local communities.

In a study comparing display energy certificates for schools across the UK (Godoy-Shimizu, Armitage, Steemers & Chenvidyakarn, 2011) it was found that there is a large variation in the amount of energy used both in terms of floor area (per m^2) and per pupil. When compared with historic data there is a general reduction in fossil fuel heating required, presumably due to better insulation levels over time as schools are refurbished or new ones built, although this reduction could be attributed to higher pupil densities or increased internal heat gains. However, any carbon saving is offset by a larger increase in the electricity requirements of the schools. The new academies (HMSO, 2010) perform particularly badly compared to primary and secondary schools, Godoy-Shimizu et al. (2011) state that "the significantly higher emissions associated with the academies is unexpected as they tend to be newer schools, recently built or refurbished." The increase is due to electricity consumption attributed to increased usage of educational equipment, computers and greater implementation of buildings services. Many new schools have been built in the recent past across the UK; more are planned for construction in the future. Evidence shows there has been some improvement in the fossil fuel energy usage of schools but that increased electrical consumption means that carbon emissions are still increasing. Given the need for significant nation-wide carbon emissions reductions by 2050 this suggests further work is needed to understand how emissions can be reduced in new schools. This paper aims to examine which drivers and barriers to low carbon design that have been identified in the literature. Then by drawing upon the experiences of a panel of experts with varied backgrounds and roles within the design team, identify which are perceived as the greatest barriers to the design of low carbon schools. It is hoped through this process that common features of the greatest barriers can be identified and hence addressed, making the design of low carbon schools easier to achieve in practice.

2. Drivers and Barriers

Clearly there are obstacles to achieving low carbon design in schools, whether cost, regulatory, communication-based, procurement or simply risk aversion. Unfortunately the construction industry is distinctive in its fragmentation. It is characterised by a wide range of sub-contractors being used, ostensibly for their individual skill sets. This does tend to minimise risk, which is often held aloft as another key driver for this method of operation. Such sub-contractors often perceive the contractor in the chain directly above them as the most important 'client', rather than the end-user of the building (Zuo, Read, Pullen & Shi, 2012; Williams & Dair, 2007). Because of this limited involvement in the project, there is little incentive to reduce energy use through good design. This lack of a collaborative design process can lead to the building design not reflecting the intended use or the building occupants not using the building services as intended. This situation can be avoided if the client is aware of the issues, educated and proactive, ensuring that relevant information about the buildings usage is passed to the relevant parties. While the client can guide the design there is still the barrier for low carbon school projects that the client is not the end user and their vision may not reflect the reality of how the building will be used in practice.

Within an organisation, decision-making is not just guided by individual preferences but is also framed by the perceived goals and interests of the organisation and other associated stakeholders. Studies have shown that individuals who hold senior positions and are most embedded within an organisation are more resistant to change, particularly where change is perceived as a departure from traditional practices (Morton, Bretschneider, Coley & Kershaw, 2011; Van Knippenburg, Van Knippenburg, Monden & de Lima, 2002). Another deterrent to low carbon design identified by Williams and Dair (2007) is the unreliability or the perceived unreliability of sustainable products and systems. Stakeholders were adverse to the perceived risk of using what they consider to be untested technologies.

Morton et al. (2011) conducted a study into the perceptions about climate change and willingness to change current practices within the building industry. The study indicated that many individuals considered their organisation to be involved in practices relevant to climate change. When investigated further these practices were mainly related to sustainability and carbon emissions reduction (climate change mitigation). As such there is some overlap with the study presented in this paper. Morton et al. (2011) noted that the most salient limitations associated with current practices were time and cost. It was inferred from participant responses that it was perceived that clients associated environmental considerations with increased cost, and that they would be unwilling to bear this cost except in so far as it was necessary to meet government requirements. These views are confirmed in another study (Williams & Dair, 2007), which concluded that the high cost of some sustainable measures is a major barrier to low carbon buildings compared to traditional buildings. This is exhibited by this response from one individual (Morton et al., 2011):

"*The sustainable, low energy solution usually costs more and requires more design input/expertise. Client organisations still often want to spend the minimum time and money to achieve a suitable building to meet current regulations.*"

Furthermore, participants indicated that the primary current activity to address climate change was to adhere to industry guidelines such as BREEAM. It was perceived that guidelines provided clear standards, were effective and made environmental issues more routine. There was evidence that this activity is limited by the voluntary nature of the guidance and their limited focus. There is also the issue of the client incorrectly identifying the most relevant standard to target, for instance while BREEAM is a well known standard in the UK, it is not the most targeted towards energy efficiency due to its holistic sustainability approach, instead a better standard may be for example the Passivhaus standard. This will require the design team to extract information from the client about what is desired and make suggestions accordingly.

The aim of this study is to identify which drivers and barriers are most pertinent to the design of low carbon schools. First a literature review will identify the relevant drivers and barriers appropriate to low carbon schools. The compiled list of barriers will then be narrowed down to the most pertinent barriers and obstacles to low carbon school design. This will be achieved by drawing upon the knowledge and experiences of a panel of experts in the field using a Delphi based approach (Wilson, 1991; Skulmoski, Hartman & Krahn, 2007). They will work together to refine the list of barriers and obstacles to achieve consensus over, which are the greatest obstacles. In this way the research is intended to both produce an as-definitive-as-possible list of obstacles to low carbon school design, and get an idea of how relevant these obstacles are to designers in the future. The Delphi method is acknowledged as being well suited to a research task when there is incomplete information about a problem or and issue (Skulmoski et al., 2007). The Delphi method is an iterative process by which the anonymous judgements and opinions of a panel of experts can be collected. This process allows the participants to freely express their opinions without in the absence of social pressures to conform with the opinions of others in the group. As such during the iterative process, decisions are evaluated on the basis of merit rather than that who has proposed the idea. In this way it is hoped that the Delphi method used in this study will highlight the true opinions of the whole design team rather than the opinions of just a few. Since low carbon school design is to become mandatory in the UK and it is likely that other countries will follow suit, the importance of the drivers is diminished and hence were not considered in the Delphi study. However, the perceived importance of different drivers compiled from the literature is presented here for completeness.

3. Literature Search

From a survey of existing literature, drivers and barriers pertinent to the design of low carbon buildings was compiled. Drivers and barriers that were not applicable to schools were discarded (e.g. ability to charge higher rents), similar drivers and barriers suggested by different sources were combined to form a comprehensive list. During the Delphi study additional barriers identified by the expert panel were added to the initial list. The tables below contain the final lists of drivers and barriers to low carbon school design together with their relevant literature sources.

Table 1 List of drivers and incentives for low carbon school design.

Driver	Source
Building regulations Part L and/or other legislation (e.g. regional)	Osmani & O'Reilley (2009); Zuo et al. (2012); Adeyeye, Osmani & Brown (2007); Sodagar & Fieldson (2008); Sunikka (2006).
Government policies and guidelines	Osmani & O'Reilley (2009); Zuo et al. (2012); Adeyeye et al. (2007); Sodagar & Fieldson (2008); Sunikka (2006); Chan, Qian & Lam (2009)
Client requirement / desire	Adeyeye et al. (2007); Chan et al. (2009)
Preparation for new legislation (i.e. ahead of the curve)	Osmani & O'Reilley (2009); Adeyeye et al. (2007)
Lower in-use costs	Zuo et al. (2012); Adeyeye et al. (2007); Chan et al. (2009)

Government funding available	Osmani & O'Reilley (2009); Adeyeye et al. (2007)
Competitive edge (for example, in tendering or architectural competitions)	Osmani & O'Reilley (2009); Zuo et al. (2012); Adeyeye et al. (2007); Chan et al. (2009)
Company reputation	Adeyeye et al. (2007); Chan et al. (2009)
Award(s) for energy efficiency and/or innovative building design	Adeyeye et al. (2007)
Lower energy consumption / emissions	Adeyeye et al. (2007); Chan et al. (2009)
Environmental implications	Osmani & O'Reilley (2009); Adeyeye et al. (2007); Chan et al. (2009)
Opportunity for innovation	Osmani & O'Reilley (2009); Adeyeye et al. (2007)
Higher building value	Osmani & O'Reilley (2009); Chan et al. (2009)

Table 2 List of barriers and obstacles for low carbon school design.

Barriers	**Source**
Policies do not account for financial implications	Zuo et al. (2012); Adeyeye et al. (2007)
Limited support from senior management	Zuo et al. (2012); Morton et al. (2011); Adeyeye et al. (2007)
Lack of financial reward for achieving low carbon	Adeyeye et al. (2007)
Client financial limitations	William & Dair (2007); Adeyeye et al. (2007); DCSF (2009a); DCSF (2010)
Insufficient evidence for financial support	Adeyeye et al. (2007)
Lack of training/knowledge on part of designers/clients/procurement	Adeyeye et al. (2007); DCSF (2009a); DCSF (2010); WBCSD (2008)
Limited products (or information) and/or service availability (i.e. supply chain)	Osmani & O'Reilley (2009); Adeyeye et al. (2007); Chan et al. (2009); Williams & Dair (2007)
Lack of client interest	Zuo et al. (2012), Williams & Dair (2007); Adeyeye et al. (2007)
Lack of awareness from stakeholders	Zuo et al. (2012), Williams & Dair (2007); Adeyeye et al. (2007); Chan et al. (2009)
Changing client requirements/priorities	Bordass, Cohen & Field (2004)
Cost savings and/or Value engineering	DCSF (2010); Bordass et al. (2004)
Lack of thorough commissioning	Bordass et al. (2004); Pegg (2007)
Systems are difficult to run for operator (especially BEMS)	Bordass et al. (2004); Pegg (2007)
Perceived extra cost incurred on sustainable buildings	Osmani & O'Reilley (2009); Morton et al. (2011); Sodagar & Fieldson (2008); Chan et al. (2009); Target Zero (2010)
Discrepancies between NCM, modelling and/or reality	DCSF (2010); Pegg (2007); Target Zero (2010); Torcellini et al. (2004)
Risk/uncertainty in innovative approaches and/or products	Williams & Dair (2007); Intrachooto & Horayangkura (2007)
Building occupants use in different way to that predicted	Intrachooto & Horayangkura (2007)
Insufficient input from specialists / input at incorrect stage	Williams & Dair (2007); Intrachooto & Horayangkura (2007)
Sustainable features not included from outset to ensure competitive tender price	Intrachooto & Horayangkura (2007)
Insufficient financing for studies / research into energy efficient innovation	Intrachooto & Horayangkura (2007)
Local contractor inexperience with innovative systems	Sujana, Noguchi & Barr (2009)
Modern school requirements (IT, out of hours operation) raises energy consumption problematically	DCSF (2010); Pegg (2007)

Non-integrated design team	WBCSD (2008); Pegg (2007)
Uncertainty in the definition of zero carbon	Osmani & O'Reilley (2009); Zuo et al. (2012)
Poor design/procurement procedures	DCSF (2009a)
Other 'sustainability' issues take priority	Williams & Dair (2007)
Measures may be restricted or prevented by regulator action	Zuo et al. (2012); Williams & Dair (2007)
Site hinders low or zero carbon design	Williams & Dair (2007)
Contractors not working to level required for building resilience	Bordass et al. (2004)
Time constraints (tendering/design) lead to incorrect specification	Sorrell (2003)

We can see from Tables 1 and 2 that there are more barriers identified in the literature than drivers for low carbon school design. This is in agreement with other studies (Zuo et al., 2012) where interviews with industry professionals identified more barriers than drivers to the low carbon design of commercial developments. This is a worrying state of affairs, as the more risk adverse organisation will likely be dissuaded from low carbon design. In several studies, regulation has been the greatest driver followed by guidance and policies (Osmani & O'Reilley, 2009; Adeyeye et al., 2007; Chan et al., 2009). As we move chronologically through the literature the importance of regulatory drivers decreases in favour of the awareness of the client and design team of environmental issues (Zuo et al., 2012) and energy costs and whole life costs (Zuo et al., 2012; Adeyeye et al., 2007; Chan et al., 2009). This is an interesting shift and suggests that clients are becoming more interested in the sustainability of buildings, either for social or financial reasons. It is important to note however that not all barriers and drivers have equivalent weight and although more barriers have been identified than drivers, some drivers such as legislation will likely overcome the majority of barriers.

Using the survey results presented in the literature (Osmani & O'Reilley, 2009; Adeyeye et al., 2007; Chan et al., 2009) the relative importance of the different drivers was estimated. The percentage of participants in each study who rated a driver as very important or equivalent was averaged, weighted according to the number of participants in each study. This was considered to be the fairest way to combine the results of the four studies, with varying numbers of participants. Figure 1 shows the relative importance of the different drivers estimated by this method. We see that when we consider the weighted relative importance of drivers from the different studies that there are a few common topics that are considered greater drivers than others, primarily lower in-use costs (incorporating: lower running costs, increased fuel prices and reduced lifecycle costs). This is a similar driver to environmental implications, reduced energy consumption, client desires (if financially motivated) and even building regulations. However, these drivers were considered separately in the literature studies and received different responses from participants. From this we can conclude that while these drivers are linked by a common theme there are distinguishing features in the minds of the participants.

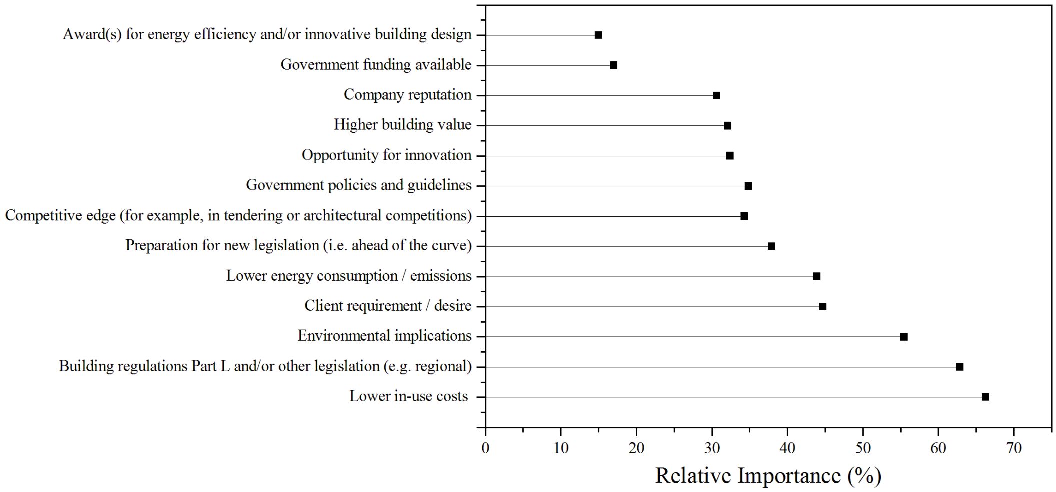

Figure 1 Plot of the relative importance of different drivers compiled from the literature.

In terms of barriers to low carbon design the largest barriers identified have been client financial limitations (Adeyeye et al., 2007) and lack of interest/awareness from client and stakeholders (Zuo et al., 2012; Williams & Dair (2007); Adeyeye et al., 2007). The barriers compiled from the literature search are generic with respect to low carbon buildings, with the individual studies referenced typically examining housing or offices. Schools are different; the client is typically not the tenant and hence does not benefit from the financial savings associated with improved efficiency. Additionally there are financial constraints associated with current austerity measures that may not be present on other projects. Also the different requirements from the building, client desires and those of the end user mean that the barriers identified that are prevalent for low carbon houses and offices may not apply or are significantly diminished in favour of other barriers. Additionally as time has progressed the changes to the drivers seen in the literature may have altered the importance of the barriers identified. A Delphi study of a panel of experts in low carbon school design has been used here to identify the relative importance of the barriers highlighted by the literature search in the context of low carbon school design, with the aim of filling a gap in the existing literature.

4. The Delphi Study

In order to assess which are the most important barriers to efficient low carbon school design, we need to draw upon the experiences of relevant stakeholders and practitioners who have been previously involved in a low carbon school project. The aim is to draw on their experiences and their perceptions of what are the most pertinent barriers that could hinder future low carbon school projects. The Delphi method used allows the surveyed participants to express their views in the absence peer pressure, allowing us to explore the barriers perceived by different members of the design team. The assessment of drivers in the Delphi study was not considered as our target participants have already worked on low carbon school projects and we wish to assess which barriers were encountered and are considered most relevant to the large-scale role out of low carbon schools in the future. Additionally drivers such as increased funding that has previously been available for exemplar schools is no longer available and low or zero carbon school designs are soon to be expected (mandatory in the UK from 2016). Hence regulation will likely remain one of the key drivers for the foreseeable future.

Design teams were approached and asked to participate in a multiple stage web survey to collect their opinions and experiences using the Delphi method. The Delphi methodology can be defined as a social survey technique involving polling experts for predictions and views on important demographic, political, economic, technological and social trends (Wilson, 1991). The Delphi method is a process from extracting tacit knowledge from a group of experts using a series of questionnaires and opinion feedback. The Delphi method was chosen as the most appropriate method for this study as the identification and confirmation of barriers to low carbon design is not a numerical exercise or well suited to precise analytical techniques, but instead suited to the collective opinion of a panel of experts who can draw upon their own experiences and backgrounds from within the building industry.

Organisations contacted to populate the expert panel were chosen based on low carbon school projects the organisation had worked upon previously. The selection criteria for individuals from these organisations were as follows: a) a member of a professional body (such as CIBSE, RIBA or RICS in the UK) or are client side, b) have participated in the construction of a low carbon school, either as a member of the design team or as another relevant stakeholder. Twelve individuals from ten different organisations including local authorities, architectural practices and consulting engineering firms, varying in size from local practices to national companies were surveyed. Participants were limited to two from any one organisation to ensure a spread of views from various projects. When there was a choice, individuals were chosen to provide variety in expertise and a spread of seniority for the panel. This approach was designed to anonymously capture a diverse range of views from different roles within design teams. A summary table of the roles of the different individuals included in the panel is shown below:

Table 3 List of the various roles of members of the expert panel.

Participant	**Role**
1	Client side
2	Architectural engineer
3	Thermal modelling / Engineer
4	Architectural engineer
5	Sustainability consultant / Engineer
6	Mechanical services engineer
7	Quantity surveyor
8	Client side
9	Sustainability consultant / Engineer
10	Mechanical services engineer
11	Architect
12	Architect

In the surveys, participants were asked to rank the different barriers from 1-4 with 1 being highly relevant and 4 being least relevant, the method is summarised below:

Ranking
1. Very important obstacle to low carbon school design

2.	Important obstacle to low carbon school design
3.	Relevant obstacle to low carbon school design
4.	Not a relevant obstacle to low carbon school design

- Any question with a median of ≥3 is highlighted for further consideration (as it may be rejected by the focus group)
- The means of these items are then checked. Any with a mean of ≥3 is automatically passed to the 2nd round for confirmation of rejection. Any with a mean of <3 then comes under the 80% consensus rule. In this case, any question with 20%+ scores of 4 (not a relevant obstacle) is passed to the 2nd round for confirmation of rejection.
- All other items are considered accepted by the focus group as obstacles that may affect low carbon school design.

Additional obstacles to low carbon school design

- Compile a list of all additional obstacles to low carbon school design suggested by expert participants.
- Merge any additional obstacles that are very similar

Alterations to existing obstacles

- Analyse and list any suggestions for alterations to existing obstacles from participant feedback (merge, separate, refine descriptions).
- Ensure no repetition of obstacles.

This process is repeated over multiple rounds until a consensus is reached about the relative importance of different obstacles. For this study 4 rounds were required to reach consensus from the different participants.

5. Results

The panel of experts assessed the obstacles over the different rounds of the Delphi study. The results of the Delphi survey are shown below in figure 2 with obstacles allotted different levels of importance according to the medians of the survey responses (i.e very important ≤1.5, 1.5< important ≤2.5, 2.5< relevant ≤3.5, not a relevant obstacle >3.5).

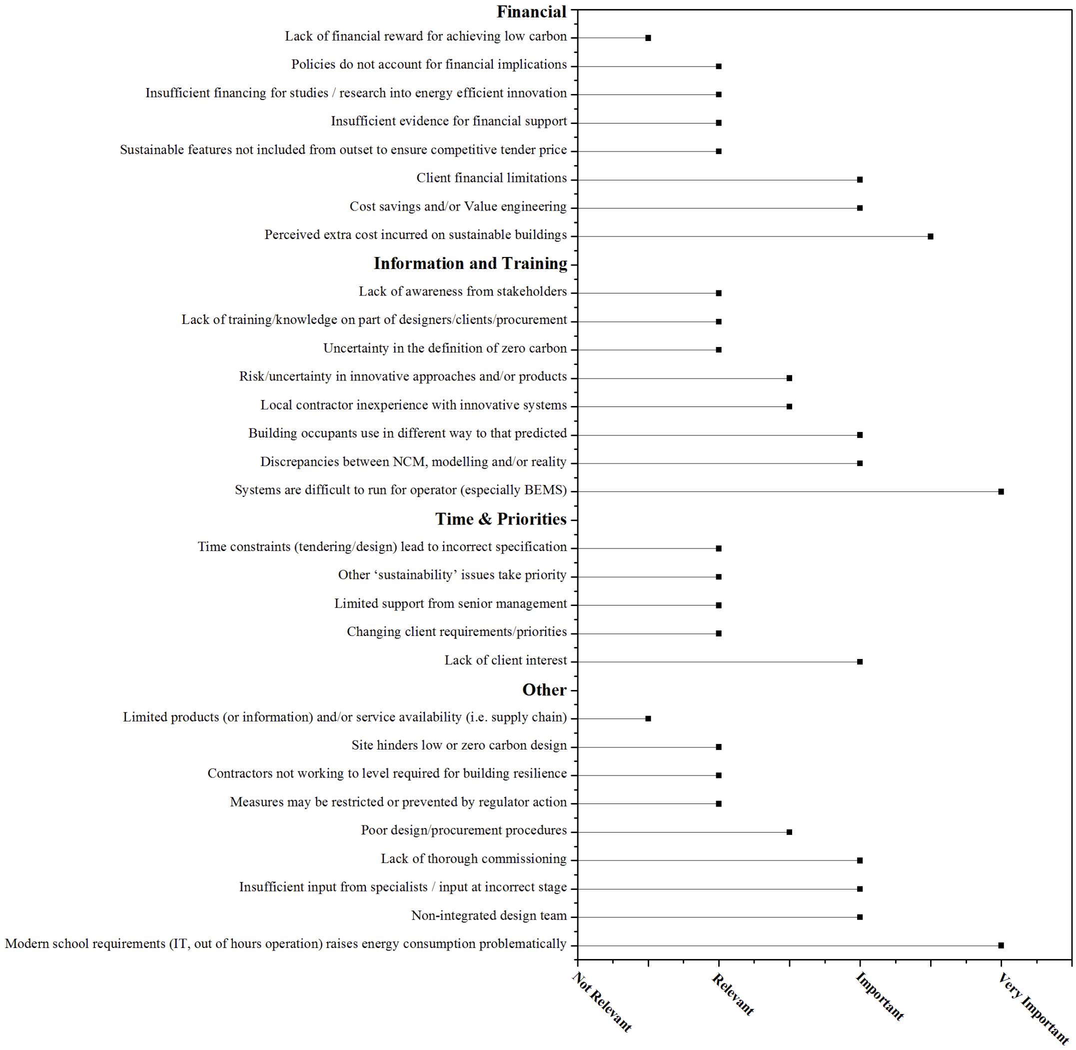

Figure 2 Barriers and their relative importance assigned by expert panel.

From the list of barriers and obstacles presented in table 2 and figure 2 the obstacles that were perceived to be a 'very important obstacle to low carbon school design' (median ≤1.5) are:

1. "Modern school requirements (IT, out of hours operation) raises energy consumption problematically" (median = 1, mean = 1.5, standard deviation = 0.67)
2. "Systems are difficult to run for operator (especially BEMS)" (median = 1, mean = 1.7, standard deviation = 0.96)
3. "Perceived extra cost incurred on sustainable buildings" (median = 1.5, mean = 1.8, standard deviation = 1.02)

While the least relevant obstacles to low carbon school design are:

1. "Lack of financial reward for achieving low carbon" (median = 3.5, mean = 3.5, standard deviation = 0.52)
2. "Limited products (or information) and/or service availability (i.e. supply chain)" (median = 3.5, mean = 3.4, standard deviation = 0.66)
3. "Sustainable features not included from outset to ensure competitive tender price" (median = 3, mean = 3.1, standard deviation = 0.52)

The participants were invited to comment on different questions to justify their position. Some of the comments show the mixed backgrounds of the survey participants but also illustrate the breath of the challenge in achieving low carbon school design. Modern school requirements of longer operating hours and increased computer and equipment usage in modern schools was identified as the greatest barrier to achieving low carbon schools, one participant indicates that:

"ICT service providers are rarely aware of equipment power consumptions and efficiencies, and even less aware of energy consumption comparisons between different equipment manufacturers. More/better energy efficiency data would help." – Sustainability consultant / Engineer.

While another participant indicates that better modelling should be able to overcome this issue:

"Default operating times / occupancy / ICT in models don't in any sense reflect reality – the best design teams take this into account." – Client side.

More detailed information about the usage of the schools and what appliances are used and when will allow designers to make better decisions regarding heating and ventilation strategies and to better size equipment and design control strategies, thereby reducing energy wastage. With an increasing amount of technology now being designed into schools the ease of use of the technology is also an important issue so as to minimise energy wastage. The complexity of building management systems was identified as a major barrier with one participant commenting:

"As is always the case with building management systems – very few people managing buildings understand them and the building mechanical/electrical systems as they can sometimes be too complicated." – Mechanical services engineer.

However, others indicated that this issue could not be designed for, but could be overcome with proper training or greater involvement of the end user within the design team:

"Very frustrating, often outside of the design teams control" – Sustainability consultant / Engineer.

"If the end user has not been involved they won't understand the system leading to waste" – Architectural engineer.

It is interesting that the lack of understanding of building management systems was ranked as a more important issue than lack of thorough commissioning, indicating that design teams believe that the users are the cause of this issue (high energy usage) rather than the industry. Last of the 'very important' barriers is the perceived cost of low carbon design and technologies. Comments for this barrier highlight the additional problem for schools that the client is not typically the end user of the building as might be the case with domestic or commercial low carbon building projects. This raises problems with life cycle costing as the client, typically the local authority does not see the savings but only the potentially higher capital cost.

"Low carbon options are more expensive when the client does not benefit from the revenue savings, client = local authority, user = school." – Architectural engineer

This issue may well be reduced for schools where the capital and running costs are covered by the same organisation, such as the new Academies or Trust schools in the UK (HMSO, 2010). However, other participants while acknowledging this issue indicate that it is the design teams job to educate the client and stakeholders about the reality of different low carbon options:

"It is on the design team to change this wrong perception and to produce specific comparison studies showing alternative options together with cost implications and CO_2 reductions." – Architect.

The individual who made the above comment ranked this issue as a very important obstacle indicating that this in his eyes is not yet common practice or even easy to achieve. This issue seems to have mixed opinions from other design team members, with one participant indicating that the requirement for payback period is unnecessary while others indicating that the add-on nature of many low carbon design features makes them ideal for reducing capital costs to meet budget requirements.

"Sustainability seems to be one of the first targets due to its visibility, need to be greener than green. Do we ask for the payback period of all other elements?" – Client side.

"Low Carbon initiatives can be withdrawn if budget savings are required." – Architect and *"Low Carbon Technologies are cut every time in value engineering" – Architectural engineer.*

In terms of the barriers identified as being least relevant to low carbon school design, the lack of financial reward was perceived to be least relevant with individuals commenting:

"The reward is knowledge and marketing" – Client side and *"Not sure why the design team should be rewarded for doing their job." – Mechanical services engineer.*

The issue of sustainable features not being included from the outset to improve the competitiveness of the tender price received mixed comments, with one individual only ranking the issue as 'relevant' commented:

"Practically an issue on every project!" Sustainability consultant / Engineer.

While others indicated that this was commonplace but not necessarily an obstacle to low carbon design:

"Minimal targets are a must at tender stage and should not be an obstruction" – Architect and *"Truly low carbon design can be achieved even without increasing capital cost. Good integrated & interdisciplinary design since the early stages is crucial." – Architect.*

6. Discussion

This paper summarises the drivers and barriers to low carbon building design identified in the literature. The Delphi study presented here illustrates the views of members of low carbon school design teams on the relevance of the different barriers identified to low carbon school design. While none of the barriers identified from the literature were dismissed completely (median >3.5), under half were identified as being 'important' or 'very important' barriers to low carbon school design. A common concept was the perceived expense of low carbon schools, both in terms of the lack of client budget and the in-use savings not being of benefit to the local authority client who meets the capital cost. Other key concepts were a lack of training of end users both in terms of building management systems and for unregulated small power energy uses not considered during design. This is highlighted by the following comments:

"The best green building in the world could be the most energy consuming if the occupants used it in the wrong way," – Architect "Schools for instance have weekend and night activities that were not fed into the design" – Mechanical services engineer and *"Quite often the case (higher than predicted energy use) for unregulated energy use and systems controls. Lack of training or unwillingness to use controls leads to waste." – Client side.*

The soft landings framework (BSRIA), which encourages communication between the design team and the end users, was given as an example of how to overcome this issue. This should also help overcome other issues highlighted by the expert panel such as the lack of design team integration and how some members of the design team (especially mechanical engineers) are not consulted soon enough to influence the overall design.

"This is the biggest problem because coming in too late means decision have already been made – working against the status quo is impossible" – Sustainability consultant / Engineer.

The lack of an integrated design team is cited as being a major barrier with traditional roles and practices not being best suited to low carbon design:

"The traditional architect led design team is a hindrance to low carbon design, as the low carbon design engineers are subservient to the architect." – Mechanical services engineer.

It should be noted that barriers apparent on one project might not manifest on another project. However, for a barrier to be ranked as important or very important in the Delphi survey then there has to be a consensus from the participants, some of whom will have worked on several low carbon school design projects. For this reason it is reasonable to accept the relative importance of the various barriers despite the finite size and experience of the expert panel.

From the opinions presented by the expert panel it does not seem that any of the obstacles to low carbon school design are insurmountable. It is suggested by comments from the expert panel that, greater communication within the design team and between the design team and the client and end users could overcome the majority of the barriers facing the implementation of low carbon school design as a matter of course. However, there is also evidence that this is not currently happening with one participant stating:

"I have not come across a fully integrated multidisciplinary team working collaboratively yet." – Architect.

It is suggested by the responses presented in this paper that the architect lead team can become locked into a design, with low carbon features removed to meet budget requirements instead of altering the initial design and retaining the low carbon features. This maybe a result of the subservience to the architect that some design team members feel and may be mitigated by increased collaboration within the design team. This is a topic that requires further research, as it is unlikely to be limited only to low carbon school designs.

Clearly for mainstream low or even zero carbon school design to become a reality there is a lot of work that needs to be done to update current practices and improve communication between clients, users and design teams and within the design teams themselves to better incorporate low carbon technologies and systems within school design. This is more relevant for schools than for say offices or domestic buildings as the client commissioning the building is typically not the user and is not involved in the day to day running of the building. As such it is necessary to ensure that specific requirements about how and when the building is to be used is passed up the chain to the design team and conversely that information about how to correctly use the building services are passed down to the end users. However, merely reducing the barriers may not be enough, maximising the drivers and incentives will also help make low carbon school design commonplace. The key drivers for low carbon design identified in the literature are associated with reduced running costs and carbon emissions, the emphasis should be on the design team to communicate to the client and with other team members the benefits of low carbon design and the potential savings. This is especially important with the current austerity measures where the cost of new school buildings is being driven down and as a result may be designed only to meet building regulations. There is also the issue for school design projects where the client does not necessarily benefit from lower lifecycle costs. However, it seems the simplest route to achieving mainstream low carbon school design is better communication between the invested parties, which has the potential to not only highlight drivers and incentives but also to negate some of the barriers and obstacles.

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